The Evolution of a 10 metre Multi-Element Beam

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Many amateurs who construct their own beam antennas are content to reproduce in every detail a published design and accept the resulting performance without question. VK3YX has instead carried through a programme of investigation from dipole to 5-element beam, adding one element at a time. He found the results most informative and now shares them with us all.

To approach a job like this, some basic tools and skills are needed plus an SWR meter, a grid dip oscillator, a dummy load, an impedance bridge and a support for the aerial. The top of the mast must be above houses, trees and other aerials. Easy access to the top of the mast is essential. For maximum experimental benefit it should be possible, without much physical effort, to lower the beam within ten minutes.

The first test was to check the 50 ohm coaxial cable. With one end terminated in the 50 ohm dummy load and the other end in a one turn link, the grid dipper, as hoped, gave no sharp dips between 27-31 MHz. After replacing the one turn link with a plug and connecting the cable to the SWR meter, the reading was unity, both before and after installing on the mast.

ciation of resonance. To quote from William I. Orr W6SAI, in his wire antenna handbook:

"For any antenna there is one frequency, called the resonant frequency, at which various characteristics of the antenna are in a state of electrical balance, and at which frequency the antenna is in a condition of maximum efficiency. The resonant frequency is a function of the electrical length of the antenna, which may or may not bear a relationship to the physical length in feet and inches. Any antenna may be tuned to resonance by auxiliary gadgets, but such devices may be a nuisance and of questionable efficiency. A resonant antenna requires no such devices and is a simple and effective radiator and receiver of radio energy."

The dipole was mounted in the operating position with cable connected, as in Photo 1. Resonance was checked with the GDO and found to be outside the low end of the band. By cutting off short lengths from each end of the element the desired frequency was reached. An SWR check agreed roughly with the GDO and was accepted. Unity SWR could not be achieved as the dipole impedance is greater than 50 ohms.

PHOTO 1: Start of the experiment, later became reference dipole.

A boom was assembled as in Fig. 2, using coach bolts and wood screws. Element lengths were re-checked after assembly. Photo 2 shows the antenna.

Under test, the SWR was found to be unity and the resonance sharper and slightly lower in frequency. This is a natural phenomenon, it just has to do this.

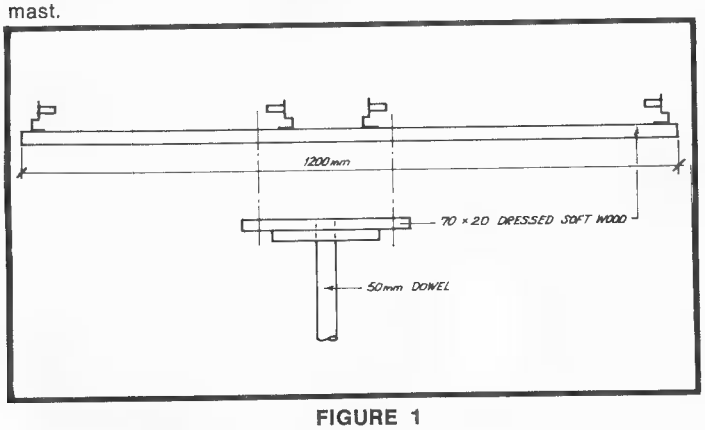

FIGURE 1

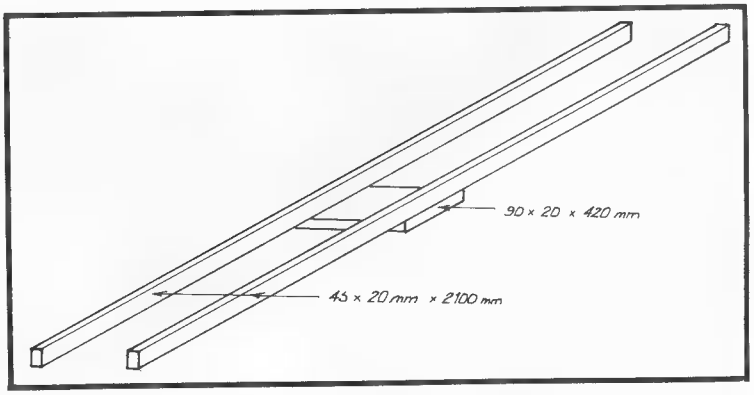

FIGURE 2

Construction began. The radiator of ½ inch aluminium tubing, was 8 feet long on each side. The opening in the centre was 25 mm, fixing hardware mainly cadmium-plated, insulators were plastic curtain rod fixtures and the board was 20 mm by 70 mm by 1.2m softwood. See Fig. 1.

RESONANCE

It is essential for understanding the experimental results to have a clear appre-

Many contacts (some DX) were worked on this dipole, including W6, D, XE, ZL, I, in the four weeks before venturing to the next step.

REFLECTOR

The second element, to be used as a reflector, was made 5 per cent longer than the measured length of the dipole. It was fitted in the same way as the radiator to a timber board with four curtain fixtures.

This beam was used successfully for some time before further development and enabled contacts to be made with KA, OH, BK, G, OZ, RA.

BALUN

The centre fed radiator is a balanced circuit, but coaxial cable is an unbalanced line. To achieve efficient operation a balanced to unbalanced balun is needed. There are many commercial baluns on the

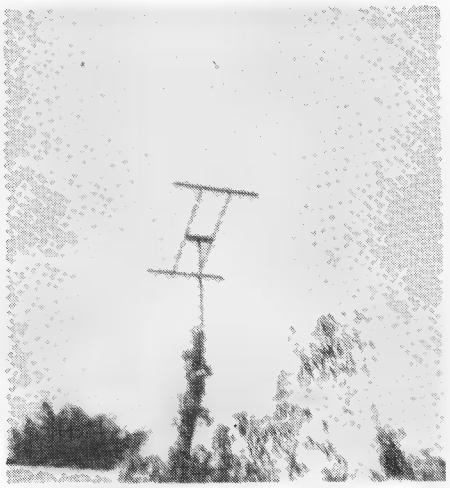

PHOTO 2: Two element prototype.

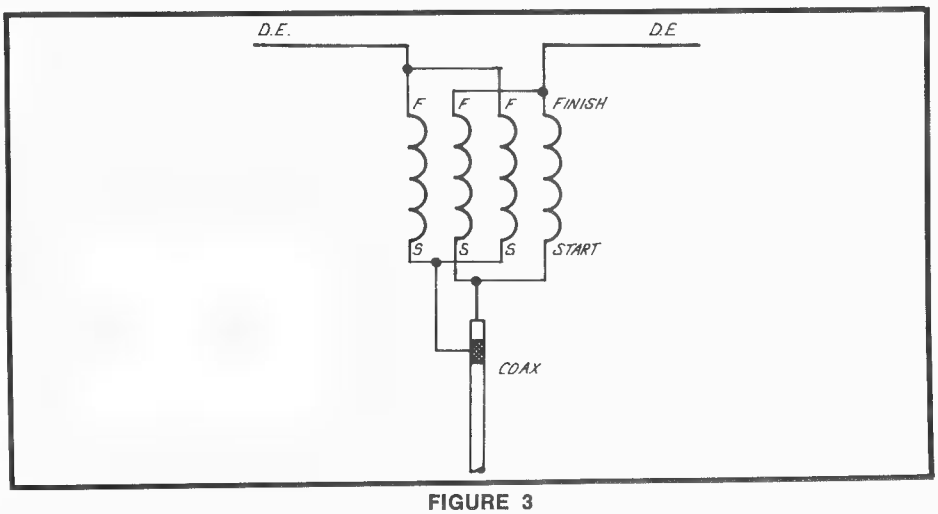

FIGURE 3

market, but most are wide band and maximum efficiency might not be at 30 MHz.

A balun kit was purchased from "Uncle Dick". Wound as specified in the leaflet, the balun seemed appropriate for lower frequencies, but on 10m introduced inductance in the centre of the radiator, lowering the resonance frequency, thereby needing reduction of radiator length. The final balun had only seven multifilar turns of four wires connected in two parallel pairs, as in Fig. 3. It could be inserted between cable and radiator without altering SWR or necessitating re-tuning. Moreover, feeding a dummy load SWR remained 1.0 and a VTVM showed equal voltage between the cable braid and each of the outputs. The balun was used successfully in different configurations on ten and fifteen metres. Other windings were tried but this was found most effective. An alternative was six turns of coax on a ferrite core ring; bulky and heavy, but it performed well.

IMPEDANCE MATCHING

So far in the experiment there was only one unknown, the resonance frequency. The impedance of the antenna being close to 50 ohms needed no special matching.

To achieve maximum efficiency the matching between cable and antenna has to be perfect. Energy transfer is maximum when cable and antenna impedances are equal. SWR is then 1.0.

The continuous battle for unity SWR is to achieve this accurate matching. Finally, some wise words from one of my lecturers from the late 1940s. He was an older man with a grey beard and a voice like Winston Churchill.

"My dear gentlemen, whatever is wrong on one end of the cable cannot, and I repeat cannot be fixed at the other end of the cable."

DIRECTOR

The next logical step was three elements on a 0.2 wavelength boom, making the distance between elements 0.1 wavelength. See Photo 3. More gain, but less bandwidth, was expected. This beam was rather small, weighing only 3 kg, and was used to experiment with different matching configurations, gaining some experience with low impedance antennas. The new (director) element was made 5 per cent shorter than the driven element. Resonance was expected exactly at the design frequency, the effect of the 5 per cent longer reflector and the 5 per cent shorter director cancelling out; however unity SWR was found at a slightly lower frequency. The antenna was re-tuned to the design frequency by cutting 10 mm at a time off the tips of the driven element. Later, the driven element was made adjustable, using ⅝ inch and ½ inch telescoping tubing secured together with a hose clip over a lengthwise saw-cut in the ⅝ tubing.

The three-element close-spaced beam has less than 50 ohm impedance so needs a matching device. The Beta Match with balun proved most successful, easy to make and adjust. Some authors refer to it as Inducto Match. The Hy-Gain Catalogue refers to it in more detail:

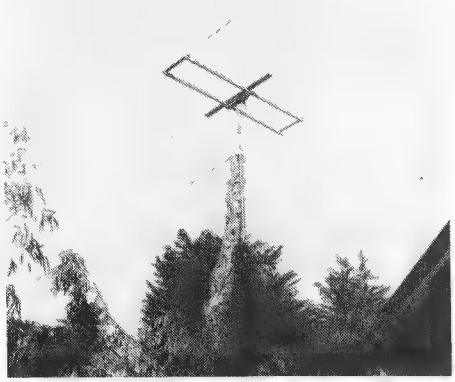

PHOTO 3: Three element beam. Note shorter support for reflector and director.

"The exclusive Beta Match provides the precise amount of inductive reactance to the characteristics capacitive reactance of a half-wave centre fed element to achieve the resisitive impedance required to insure an optimum transfer of electrical energy with minimum SWR. The Beta Match and balun eliminates pattern distortion and spurious side and back lobes to ensure an extremely clean pattern."

Later the Beta Match was found to be TVI free. Very good contacts were made with SM, OE, VU, plenty of UL, UA, UI and even more Js.

WIDE SPACING

All textbooks quote far better figures for gain, back-to-front ratio and bandwidth for wider spacing between elements. Except for matching between cable and radiator no change was required but a longer boom. So a boom support and extension as in Fig. 4 was fitted with coach bolts. For more pessimistic constructors, let me assure you that this construction (with up to five elements) survived all storms in 1978-1979.

The first attempt to match this beam in the same way as the closed-spaced one failed. Unity SWR could not be achieved, and after ten attempts the last line in the notebook reads "impossible". A 1 : 4 impedance ratio balun was wound, tapped to the radiator in delta match fashion some 50 cm from centre and the centre shorted across. This produced unity SWR spot on design frequency.

And what a beam it was! Like having an extra pre-amp in the receiver and a linear on the transmitter. More bandwidth, better reports and all the things an amateur could wish for. Unfortunately, some slight TVI was reported by the family. Contacts were made with DA, DF, OZ, SM and Gs.

MORE MATCHING

At this stage of the experiment, with the three element beam working well, reasons were sought for the failure of the beta match. Cable length was investigated in the hope that the original GDO test, showing correct cable operation, might have been insufficient.

The length of the cable was made an exact number of half wave lengths. Theoretically, then, the impedance bridge

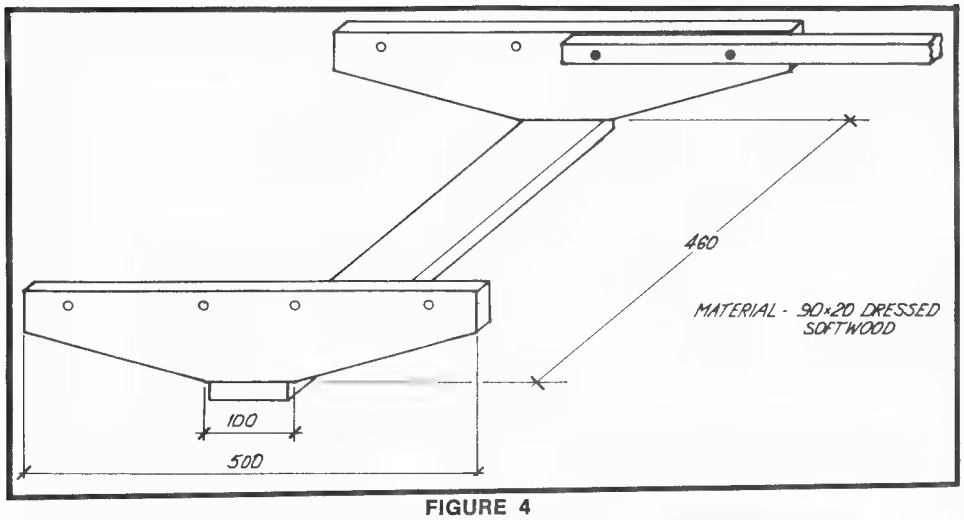

FIGURE 4

would indicate the actual impedance of the antenna regardless of the characteristic impedance of the cable. The length was calculated assuming a velocity factor of 0.66 and necessitated reduction by approximately 50 cm. Unfortunately, no check was made whether this would make the beta match function. More tests showed the cable still to be too long. Tests were made with GDO, impedance bridge and also with a signal generator and a VTVM. While readings were not exactly identical, all measurements showed too low a resonance frequency. Eventually a further 20 cm was removed before the cable resonance was correct.

At this time, test cables were also made, one one-half wave length and one one-quarter wave length complete with plugs. The physical lengths of antenna cable and test cables were found to be integral multiples. Resonance testing with the impedance bridge on a sub-harmonic was most successful, the quarter-wave cable being tested as a half-wave at twice the frequency.

A new attempt was made to produce a beta match for the three element wide-spaced configuration.

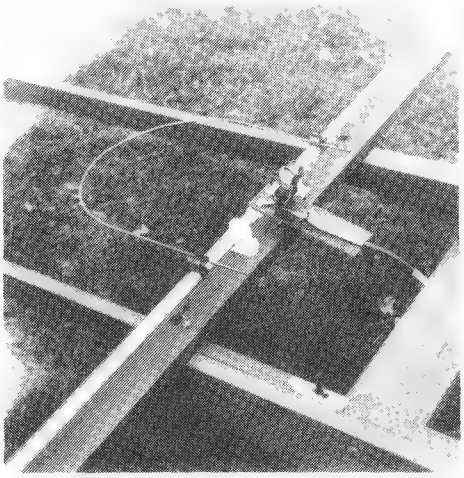

PHOTO 4: Driven element, beta match with balun (cover removed).

radiator was shortened by 5 cm to bring the resonance back to the design frequency readjusting the beta match to keep the SWR unity. No difference was found in performance, but the antenna did not receive on frequencies outside the band. This gave less QRM and quieter reception in the band.

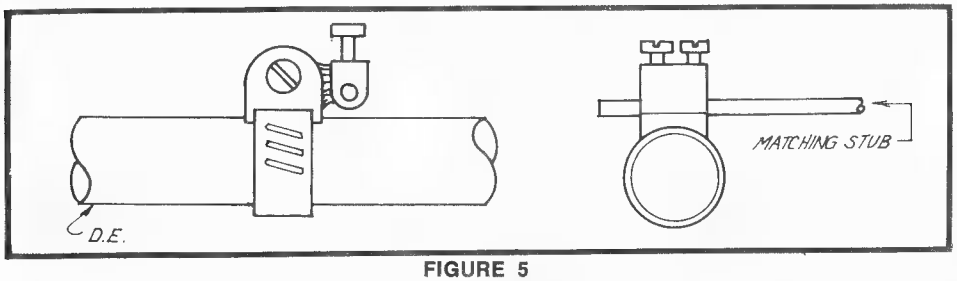

FIGURE 5

Inserts from connector strips were silver soldered to hose clips (Fig. 5), which made possible the shifting of the tapping on the radiator as well as changing the length of the matching stub. The 1 : 1 balun connected in the centre and a full length of bronze welding rod tapped on 10 cm from centre produced 1 : 1 SWR (Photo 4). However due to the inductance in the centre the resonance frequency was too low. The

Having solved the problem, it seemed incredible that a mismatched antenna and 70 cm of coax could make a mockery of impedance bridge, GDO and the SWR meter.

(This seems to have been a classic case of RF outside the coax as well as inside, thus causing misleading and incorrect measurements.—Tech. Ed.)

FOUR ELEMENTS

Very soon the question came up, could one more director be added to the antenna without changing the boom length, achieving more gain and not sacrificing too much bandwidth? Another director was produced. The previous support was thought to be over-designed and the new one was only 45 cm long of 20 x 10 mm timber, using two rod fixtures and in the centre an aluminium bracket made up from flattened tubing. See Photo 5. The new director, of the same length as the first, was fixed halfway between the first

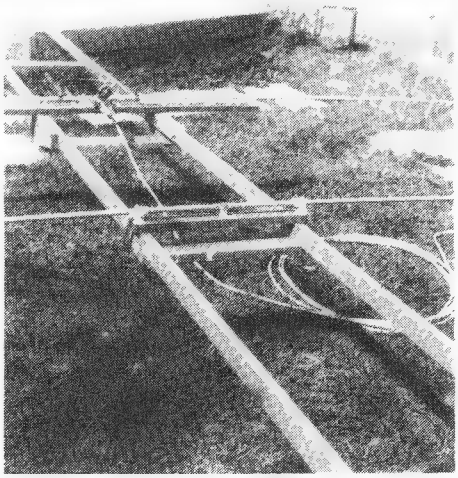

PHOTO 5: Reflector, lighter construction.

director and the driven element. Matching created no problem. The driven element was moved towards the reflector until maximum gain was achieved, at spacings of 0.1-0.12-0.18 wavelength. This was the most successful yagi produced, SWR 1.2 at 28.457 and 28.7 MHz. See Photo 6. New countries were PA, ON, HB, EA, EI, HS, A9 YB.

MORE?

Five elements on equal spacing (0.1 wavelength) were also investigated but because of lower gain and too small bandwidth this experiment was abandoned. See Photo 7. While working on this antenna we stumbled on a very elegant way of widening the bandwidth of a Yagi. Adjust the length of

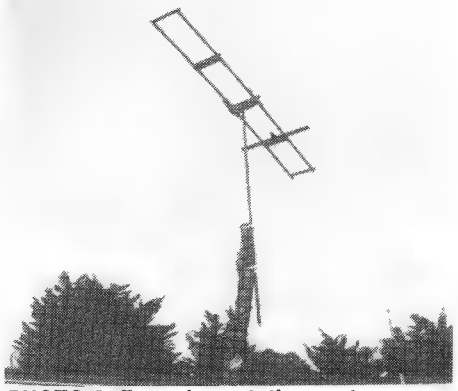

PHOTO 6: Four element, the most successful yagi produced.

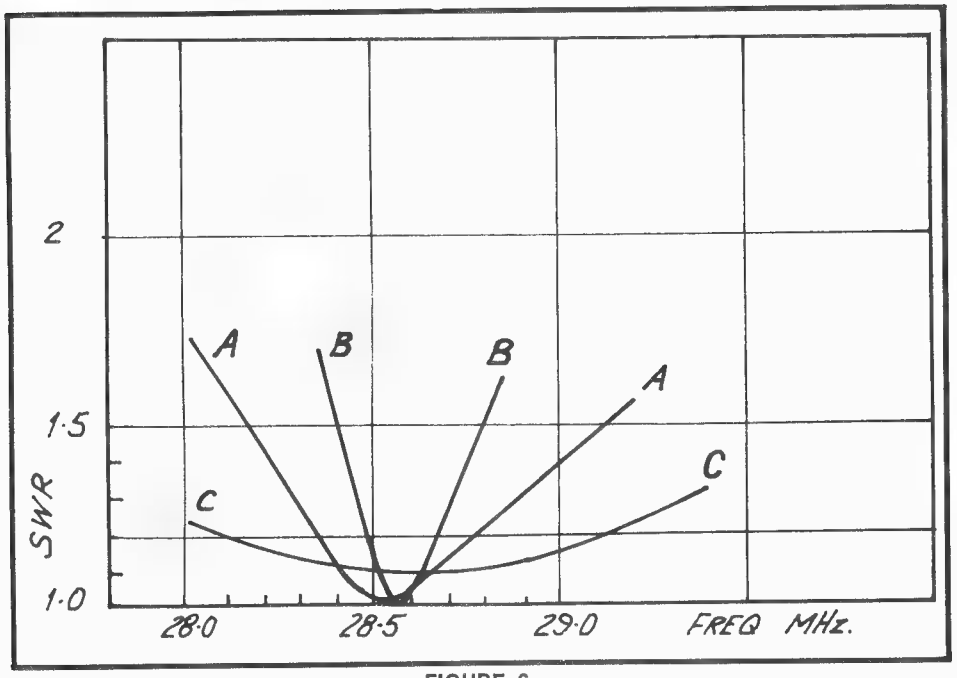

FIGURE 6

the driven element and the matching system to achieve unity SWR on a frequency 0.5 per cent higher than the design frequency. Without changing the match extend the driven element 1 per cent. SWR will be lower over a much wider portion of the band. This is a form of "stagger tuning". Needless to say, efficiency was down, particularly on the two ends of the band.

After bringing the antenna back to four elements and readjusting the beta match, some more investigating was carried out on cable length. Having on hand extension cables ¼ wave and ½ wave long enabled some very interesting observations to be made. Extending the antenna cable ½ wavelength produced no difference in performance. Extending the antenna cable ¼ wavelength impaired the performance. Unity SWR could not be achieved and the bandwidth was reduced. Most remarkable was the beacon segment; the signals around 28.2 MHz completely disappeared with the ¼ wave and ¾ wave (¼ + ½ wave) cable extension while not affected by ½ wave extension.

Stagger tuning was tried to see if this was practical with a four element yagi. It worked in the same manner as with the five element. If there is a real need to cover a wide range of the band this setting could be more effective than the correct tuning. But as there was no need for the full spectrum in this case, correct tuning was adopted. Fig. 6 gives SWR curves for A, normal tuning; B, with ¼ wave extension cable; and C, stagger tuning.

CONCLUSIONS

To withstand all Melbourne's storms ½ inch 20G aluminium tubing has sufficient strength for a 10 metre beam.

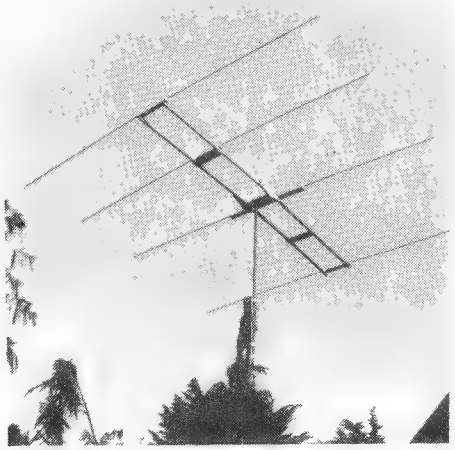

PHOTO 7: Five element — "Too many cooks spoil the broth".

After establishing the length of the dipole to resonate on the design frequency, the length of the reflector and directors can be calculated. To maintain resonance of the antenna on the design frequency only the driven element need be shortened.

Optimum performance of a balun specifically for the 10 metre band is achieved with 6 turns. Omission of the centre equalizing winding eliminates the need for returning the driven element.

If the length of transmission cable is cut to a multiple of ½ wavelength it simplifies matching and tuning adjustments. Specific length improves transmitting and receiving on frequencies away from resonance. (This is debatable!—Tech. Ed.)

The beta match with a balun is superior to the gamma match. On receive the S/N ratio is better (lower noise), and on transmit TVI was not produced.

An antenna impedance bridge is a necessity, a GDO is a luxury and an SWR indicator belongs to every transmitter. ■